

Application of CAD/CAE & Rapid Prototyping Technology in Medical Field

Mandar M. Deo^a

Tanay V. Dani^b

A. M. Wankhade^c

M.N. Syed^d

^{a,b}Final Year Mechanical Engineering Department, J.D.I.E.T., Yavatmal, 445001(M.S.), India.

^{c,d}Asst. Prof. Mechanical Engineering Department, J.D.I.E.T., Yavatmal, 445001(M.S.), India

Abstract

Now a days , one of the critical factors in competitive technology is “time to market” along with full proof design. This critical factor indicates the entire product design cycle from concept to product design to prototype to manufacturing process design to actual implementation. To have command over this critical factor Computer aided designing (CAD) and manufacturing (CAM) is taking hold as a mean of speeding the time to market for new product development. The CAD approach is used in Rapid Prototyping techniques (RPT) for design and development of new products. Use of this CAD techniques in RPT techniques shorten the time to market and further for research and development of time of new products. In this seminar we are going to discuss about the conversion of CT scan or MRI results which are taken as input and then converted in to CAD file then analyze those files with the help of CAM software then production that product with rapid prototyping. Medical applications are some of the most interesting applications of the rapid prototyping technologies. These technologies are able to produce a physical model of the anatomic structures. This model is very useful for diagnosis, surgery planning, training, and for design and manufacture of the custom implants & we are also going to discuss about the rapid prototyping techniques.

Keywords: CAD/CAM, Rapid Prototyping Technology (RPT)

1: Introduction

The scientific research in the field of structural optimization has increased very substantially during the last decades, and considerable progress has been made. This development is due to the progress in reliable general analysis tools like the finite element method, methods of design sensitivity analysis, and methods of mathematical programming, and has been strongly boosted by the exponentially increasing speed and capacity of digital computers.

This is practically made possible by using Computer Aided Design and Analysis, which accounts for completeness and accuracy of model.

Rapid Prototyping is a promising powerful technology that has the potential to revolutionize certain spheres in the ever changing and challenging field of medical science. The process involves building of prototypes or working models in relatively short time to help create and test various design features, ideas, concepts, functionality and in certain instances outcome and performance. The technology is also known by several other names like digital fabrication, 3D printing, solid imaging, solid free form fabrication, layer based manufacturing, laser prototyping, free form fabrication, and additive manufacturing. The use of Rapid prototyping for medical applications although still in early days has made impressive strides. It is used in orthopedic surgery, maxillofacial and dental reconstruction, preparation of scaffold for tissue engineering. It is used as educational tool in various fields like obstetrics, gynecology and forensic medicine to plastic surgery. It has now gained wide acceptance and is likely to have far reaching impact on how complicated cases are treated and various conditions taught in medical schools. The primary advantage of the customized bone substitute based on RP is that it can design and make the prototype of the bone substitute rapidly with the customized shape.^[7]

It has also covered fields like design & development of medical devices, planning & explaining of complex surgical operations. With use of rapid prototyping we have seen a great improvement in the field of prosthetics & implantation. It is also useful in Orthopedics, Congenital Defects, Obstetrics, Dental, Maxillofacial and other fields.

1.1: Imaging using CT scan or MRI scan:

In short, the procedure involves getting a CT scan or MRI scan of the patient. It is preferable that the CT scan is of high slice caliber and that slice thickness is of 1- 2mm. Most of the MRI and CT software give output in form of digital imaging and

communication in medicine format popularly known as DIACOM image format which is in 3-D format [6].

1.2: Changing the format of scanned file & segmentation using conversion software:

Now the data is exported in DIACOM file format. A 3D-reconstructed object has to be converted into a specific data file format for a subsequent processing. The object's data format is transformed into the .STL-file format where surfaces get triangulated [1].The conversion requires specialized software like MIMICS, 3D Doctors & AMIRA. These software process the data by segmentation using threshold technique which takes into the account the tissue density. This ensures that at the end of the segmentation process, there are pixels with value equal to or higher than the threshold value. A good model production requires a good segmentation with good resolution and small pixels. Various software available for conversion are:

- MIMICS by Materialize Analyze by the Clinique Mayo
- Amira
- SliceOmatic by TomoVision
- 3D Doctor BioBuild by Anatomics

1.3: Creation of design & its evaluation:

This step requires combined effort of surgeon, bio engineer and in some cases radiologist. It is important that unnecessary data is discarded and the data that is useful is retained. This decreases the time required for creating the model and also the material required and hence cost of production. Sometimes this data can be sent directly to machine for the production of model especially when the purpose of model is to teach students. The real use however is in surgical planning in which it is critical that the surgeon and designer brain storm to create the final prototype. There may be a need to incorporate other objects such as fixation devices, prosthesis and implants. The step may involve a surgical simulation carried out by the surgeon and creation of templates or jigs. This may require in addition to the existing converting software, computer aided designing software like Pro- Engineer, Auto CAD or Turbo CAD.



Fig. Designing using CAD software

1.4: Analysis of the created design:

In this process the model which is created in CAD software is tested with the help of Finite Element Method (FEM) or analysis software like ANSYS, NASTRAN etc. Fig. shows an ankle joint which is analyzed in ANSYS.



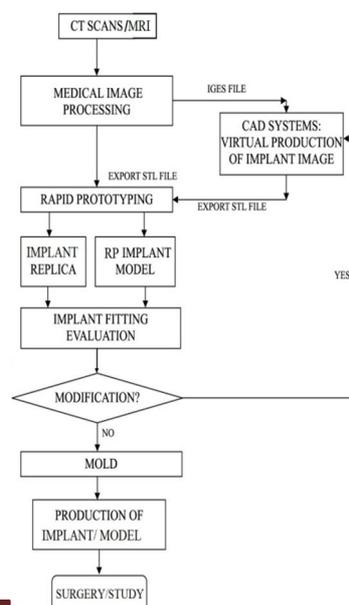
Fig.: Analysis using CAE software

1.5: Creation of the model:

There are various technologies available to create the RP model including stereo lithography (SLA), selective laser sintering (SLS), laminated object manufacturing (LOM), fused deposition modeling (FDM),and Ink Jet printing techniques. The choice of the technology depends on the need for accuracy, finish, surface appearance, number of desired colours, strength and property of the materials. It also takes a bit of innovation and planning to orient the part during production so as to ensure that minimum machine running time is taken. The model can also be made on different scale to original size like 1: 0.5, this ensures a faster turnaround time for production and sometimes especially for teaching purpose this may be convenient and sufficient.

1.6: Validation of the model:

Once the model is ready, it needs to be evaluated and validated by the team and in particular surgeon so as to ensure that it is correct and serves the purpose. The whole process stated above can be understood in the flow chart [5]



2: RP TECHNIQUES

The selection of the suitable RP technique for the manufacturing of a certain product is a very complex problem and has been addressed by some authors. In fact, the problem of investment evaluation and selection of RP technologies implies a complex multicriteria decision, depending on several factors^[2]. Many different rapid prototyping (RP) technologies have been used in the fabrication of 3D biological scaffolds for example, selective laser sintering (SLS), stereo lithography (STL) and 3D printing. However, these above mentioned fabrication technologies are limited for cell growth applications because of the methods of scaffold construction they use^[3].

2.1: Stereo lithography (SLA):

Stereo lithography creates 3-D models by tracing a low powered ultraviolet laser across a vat filled with resin. The material is cured by the laser to create a solid thin slice. The solid layer is then lowered just below the surface and the next slice formed on top of it, until the object is completed. It is regarded as a benchmark by which other technologies are judged.

2.2: Selective laser sintering (SLS)

SLS creates 3-D models out of a heat-fusible powder, such as polycarbonate or glass-filled composite nylon, by tracing a modulated laser beam across a bin covered with the powder. Heating the particles causes them to fuse or sinter together to create a solid thin slice. The solid layer is then covered by more powder and the next slice formed on top of it, until the object is completed.

The same process can be performed with a combination of low-carbon steel and thermoplastic binder powder, resulting in a 'green state' part. The binder is then burned off in a furnace and the steel particles are allowed to sinter together. The resulting steel skeleton is subsequently infiltrated with copper, resulting in a metal-composite part.

2.3: Fused deposition modeling (FDM)

FDM creates 3-D models out of heated thermoplastic material, extruded through a nozzle positioned over a computer controlled x-y table. The table is moved to accept the material until a single thin slice is formed. The next slice is built on top of it until the object is completed. FDM utilizes a variety of build materials, such as polycarbonate, polypropylene and various polyesters which are more robust than the SLA models.

2.4: Laminated object manufacturing (LOM)

In this technique, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. A feeder/collector mechanism advances the sheet over the build platform, where a base has been constructed from paper and double-sided foam tape.

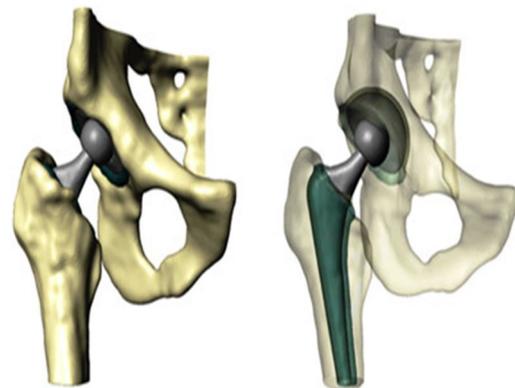
Next, a heated roller applies pressure to bond the paper to the base. A focused laser cuts the outline

of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype). Crosshatching breaks up the extra material, making it easier to remove during post-processing. During the build, the excess material provides excellent support for overhangs and thin walled sections. After the first layer is cut, the platform lowers out of the way and fresh material is advanced. The platform rises slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. Although these models are robust, it is difficult to remove unwanted region of paper from areas of complex geometry.

2.5: 3-D printing

3-D printing creates models by spraying liquid through ink-jet printer nozzles on to a layer of metallic or ceramic precursor powder, thus creating a solid thin slice. The printing process is repeated for each subsequent slice until the object is completed as a 'green-state' part. The part is then fired in a furnace to sinter the powder. The resulting skeleton object is subsequently infiltrated with metal, resulting in a full density part. This process is very fast and produces parts with a slightly grainy surface. Machines with 4 colour printing capability are available.

3: RP Medical Applications



3.1: Great improvements to the fields of prosthetics and implantation.

RP techniques are very useful in making prostheses and implants for years. The ability to quickly fit prosthesis to a patient's unique proportions is a great advantage. The techniques are also used for making hip sockets, knee joints and spinal implants for some Medical Applications of Rapid Prototyping. Both the release of and the improvement of the properties of used materials have had a significant influence on the quality of prostheses and implants made by RP. One interesting example is maxillofacial prostheses of an ear which is obtained by creating a wax cast by laser sintering of a plaster cast of existing ear. Due to RP technologies it is very easy to manufacture custom implants. The made model could be used as a negative or a master model of the custom

implant. Many researchers explored new applications of RP in this field.



Fig: On the left the intact ear - On the right the ear prosthesis.

3.2: Planning and explaining complex surgical operations.

This is very important role of RP technologies in medicine which enable pre surgery planning. The use of 3D medical models helps the surgeon to plan and perform complex surgical procedures and simulations and gives him an opportunity to study the bony structures of the patient before the surgery, to increase surgical precision, to reduce time of procedures and risk during surgery as well as costs (thus making surgery more efficient). It is convenient for preoperative planning as well as checking the implant design as shown in Figure 3(D F). Therefore, better communication between the designer and surgeon is established, because handling the solid entity is easier compared to handling contours^[4]. This is especially important in cancer surgery where tumor tissue can be clearly distinguished from healthy tissue by different color. Surgical planning is most often done with stereo lithography (SLA) where the made model has high accuracy, transparency but limited number of colors and 3DP (for more colored models, presentation of FEA results).

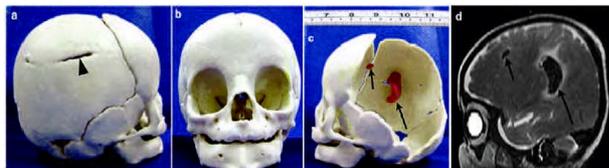


Fig: The case of a fractured skull (a-c), showing parenchymal bleed in the brain of an infant.

MR image (d) indicated the position of the bleed. The model was built combining and registering CT images, providing the skull structure, and MR images, providing the bleed volume and position.

3.3: Teaching purposes.

RP models can be used as teaching aids for students in the classroom as well as for researchers. These models can be made in many colors and provide a better illustration of anatomy, allow viewing of internal structures and much better understanding of some problems or procedures which should be

taken in concrete case. They are also used as teaching simulators.

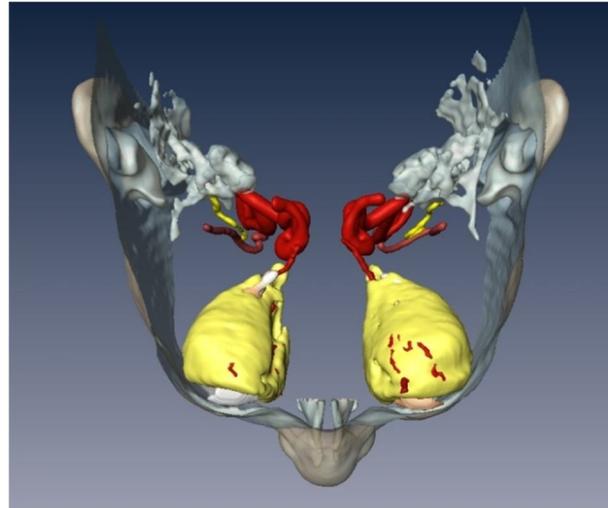


Fig: RP model to explain Anatomy

3.4: Design and manufacturing biocompatible and bioactive implants and tissue engineering.

RP technologies gave significant contribution in the field of tissue engineering through the use of biomaterials including the direct manufacture of bioactive implants. Tissue engineering is a combination of living cells and a support structure called scaffolds. RP systems like fused deposition modeling (FDM), 3D printing (3-DP) and selective laser sintering (SLS) have been proved to be convenient for making porous structures for use in tissue engineering. In this field it is essential to be able to fabricate three-dimensional scaffolds of various geometric shapes, in order to repair defects caused by accidents, surgery, or birth. FDM, SLS and 3DP can be used to fabricate a functional scaffold directly but RP systems can also be used for manufacturing a sacrificial mould to fabricate tissue-engineering scaffolds.

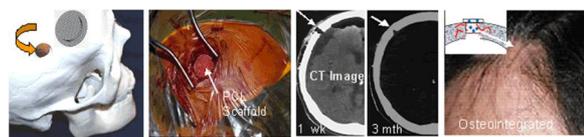


Fig: Structure created for tissues to grow and fitted in scar with help of surgery

4: Conclusion:

The CAD\CAM and Rapid Prototyping has made a significant impact in the field of biomedical engineering and surgery. Physical models enable correct identification of bone abnormality, intuitive understanding of the anatomical issues for a surgeon, implant designers and patients as well. However this is just a little step ahead. There are many unsolved medical problems and many expectations from RP in this field.

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